Mass Flux-Informed Remediation Decision Making at One of Canada’s Most Polluted Sites

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Long history of steelmaking in Sydney (1901-1988)

700,000 tons of coal tar released into Muggah Creek (Sydney Tar Ponds, STPs)

- PAHs
- Metals
- PCBs

Govt. scientists reported widespread contaminated sediment & biota in STPs & Sydney Harbour in 1980s

Remediation seen as solution
Numerous unsuccessful remediation attempts

In 2004, Govts. of Canada & NS announced a $400 m project to clean up STPs & Coke Ovens

STPs remediation consisted of solidification/stabilization (S/S) with cement

Previously *mobile* contaminants effectively *immobilised* from migrating into SH
Monitoring Effects of Remediation

- Environmental Impact Statement (EIS) & Joint Review Panel (JRP) concluded
  - “Remediation unlikely to cause significant negative environmental impacts with implementation of appropriate mitigation”

- Environmental Effects Monitoring (EEM) program designed to
  - Determine effectiveness of mitigation
  - Verify effects predictions made in EIS
  - Designed to assess positive / negative changes potentially attributed to remediation

- EEM program reviewed by key federal & provincial departments
  - GW monitoring
  - SW monitoring
  - Marine EEM Program
Marine EEM Program

- **Water Quality (WQ)**
  - 24h auto sampler
  - Water grabs (surface & near bottom)

- **Mussel Tissue**

- **Sediment Quality**
  - Sediment chemistry (grabs & traps)

- **Crab Hepatopancreas Tissue**

- **Benthic Community**
  - Inter-tidal (5 transects using quadrats)
  - Sub-tidal (sieve analysis for benthic invertebrates)

Detection of changes

- **Short term**

- **Long term**
Marine EEM Sampling

- **Spatial & temporal sampling**
- **Stations – 9-11**
  - Area 1 – Near-field
  - Area 2 – Mid-field
  - Area 3 – Far-field/reference
  - Area 4 – Sydney River Estuary
- **Sampling**
  - 2009 baseline
  - 2010 1\textsuperscript{st} yr remediation
  - 2011 2\textsuperscript{nd} yr remediation
  - 2012 3\textsuperscript{rd} yr remediation
Sediment Quality: Grabs

- Grabs used for sediment sampling
- Surface sediments (0-1 cm) sampled annually at each station
- Sediments analysed for
  - PAHs
  - Metals
  - PCBs
  - TOC etc
Sediment Quality: PAHs

- Significant increase in PAHs in Yr 1
- Some agencies called for termination of remediation after 1st year (Premature?)
DFO CSAS strong concerns & EC even requested cessation of remediation activities!
Sediment Quality: PAH Increases?

- Calculated **Mass Flux** to determine release of contaminants from site
  - 3 yrs of mass flux
- Grabs & DFO gravity SLO-CORER compared
- Triplicate sampling to assess intra-station variation
- Other potential sources using LOE approach
  - Bulk coal storage facility
  - Uncovering events?
  - Ship propeller wash
Estimates of PAH Mass Flux to SH

- Contaminant mass flux techniques help understand “mobile” vs. “immobile” contaminants
  - Gibbs & Santillan (2009); Suthersan et al. (2010)
  - Flux-informed decision-making helps develop remediation end point goals aimed at reducing off-site exposure & risk
- Reviewed numerous historical flux studies at STPs
  - Government reports
  - ERA studies
- Performed our own mass flux study (3 yrs) during remediation at STPs
  - Dillon (2011, 2012 & 2013)
- Compared against independent engineers flux estimate
  - CRA (2011)
Assumptions for PAH Flux Estimates

- **Marine**
  - Δ conc. over 15 months (Jul 2009-Oct 2010)
  - Mean concs. calculated/m² for each area over 0-1 cm horizon
  - Surface area determined for each area

- **SW**
  - Mass loadings calculated for Jan-Dec 2010
  - SW flow data provided by STPA represents inputs to North Pond
  - Concs. based on outgoing tide samples collected within ~2 h of low tide
  - Loadings based on mean, min. & RDLs concs.
  - 20% increase in total flow added to account for overflow at South Pond & overland flow

- **GW**
  - GW from eastern shore of North Pond assumed to contribute mass discharge (5 wells)
  - Mean concs. from quarterly sampling events used (Mar, Jun, Sep)
  - Hydraulic gradient of 0.005 used based on 2010 GW contours
  - 2.5 m of plume (aquifer) thickness in intertidal zone assumed
Total PAH Accumulation

- Total PAH accumulation from 2009 - 2010
  - Area 1 – 363 kg
  - Area 2 – 916 kg
  - Area 3 – 469 kg
  - Area 4 – 189 kg

- Total PAH ~2000 kg !!!!
### Sample Area

<table>
<thead>
<tr>
<th></th>
<th>Total Suspended Solids</th>
<th>Aluminum</th>
<th>Cadmium</th>
<th>Chromium</th>
<th>Copper</th>
<th>Lead</th>
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### Calculated Mass Discharge to Sydney Harbour Year 3 (2012)

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### Calculated Mass Discharge to Sydney Harbour Year 1 (2010)

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### Trends between yrs 1, 2 and 3 Mass Flux

- **D** = Decreasing
- **PD** = Potentially Decreasing
- **S** = Stable
- **PI** = Potentially Increasing
- **I** = Increasing

**Calculated Accumulated Mass in Sydney Harbour Year 3 (2012)** Corrected for 12 months (e.g., change in concentration between July 2011 to July 2012)

**Calculated Accumulated Mass in Sydney Harbour Year 2 (2011)** Corrected for 12 months (e.g., change in concentration between October 2010 and July 2011)

**Calculated Accumulated Mass in Sydney Harbour Year 1 (2010)** Corrected for 12 months (e.g., change in concentration between July 2009 to October 2010)
Estimates of PAH Fluxes to SH

- **Previous (300-800 kg/yr)**
  - 1989: 767 kg/yr (Lane & Associates, 1991)
  - 2000 & 2001: 289 kg/yr (Lee et al., 2002)

- **During Remediation (<120 kg/yr)**
  - 2010: 97 kg/yr (Dillon, 2011)
  - 2010: 119 kg/yr (CRA, 2011)
  - 2011: 17 kg/yr (Dillon, 2012)
  - 2012: 56 kg/yr (Dillon, 2013)
Sediment Quality: PAHs

- **Significant increase in PAHs in Yr 1**
  - Some agencies called for termination of remediation after 1st year (Premature?)
- **Subsequent monitoring showed a continued decrease in PAHs**
  - Not significantly different from baseline
  - Within predicted ranges reported by Smith et al. (2009)
- **EIS prediction of no significant environmental impacts in SH confirmed?**
[PAH] Increases During yr 1

- **Onsite releases from remediation activities?**
  - A more localized sediment PAH signature expected
  - ~100 kg/yr PAHs estimated flux from STPs, considerably lower than ~800 kg/yr flux estimated by JDAC (2002) & much lower than would be required to cause PAH increases in yr 1 (2000 kg)

- **Large scale uncovering event of contaminated sediments?**
  - 5 major storms between July 2009 & October 2010
  - Ship propeller wash – but not at all sites?

- **Results from 2009 could have been “unusually” low?**
  - Burial from less contaminated shallow channel sediments

- **Other potential sources (eg. bulk coal storage facility)**
  - Although this facility was also present in 2009?
**Sediment Quality: Metals**

- Little apparent temporal variation
- EIS prediction of no significant environmental impacts in SH confirmed?

<table>
<thead>
<tr>
<th>Monitoring Year</th>
<th>Baseline</th>
<th>Yr 1</th>
<th>Yr 2</th>
<th>Yr 3</th>
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<td><strong>As concentrations in surface sediment (µg g⁻¹)</strong></td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
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<tr>
<td><strong>Cd concentrations in surface sediment (µg g⁻¹)</strong></td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
<td><img src="image7.png" alt="Graph" /></td>
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<td><strong>Cu concentrations in surface sediment (µg g⁻¹)</strong></td>
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<td><img src="image10.png" alt="Graph" /></td>
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<td><strong>Hg concentrations in surface sediment (µg g⁻¹)</strong></td>
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<td><strong>Pb concentrations in surface sediment (µg g⁻¹)</strong></td>
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<td><strong>Zn concentrations in surface sediment (µg g⁻¹)</strong></td>
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Heavy Metal(s) Lives On!
## Contaminants in Various Media

<table>
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<tr>
<th>Media</th>
<th>Detection of Effects</th>
<th>PAH</th>
<th>PCB</th>
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<td>Blue mussels</td>
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<td>Not significant (Walker et al. 2013a)</td>
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→ = Stable  
↓ = Decreasing  
↑ = Potentially increasing  
nd = Not detected

Summary

- Only 17-97 kg/yr total PAH discharged in SW during 3 yrs monitoring
  - GW responsible for negligible quantities (0.002-0.005 kg/yr)

- Independent PAH flux study in yr 1 estimated 119 kg/yr (CRA, 2011)
  - Compared favourably to our 97 kg/yr estimate during same period

- PAH flux from STPs during remediation is in stark contrast to ~2000 kg loading in harbour sediment PAH concentrations during 2010

- Mass flux estimates during remediation was much lower than ~800 kg/yr PAHs discharged from STPs in 2001 (JDAC, 2002)
  - At same time, govt. studies demonstrated on-going reduction in PAH concs.
Summary

- This mass flux study informed remediation decision making by helping all stakeholders better understand “mobile” vs. “immobile” contaminants
  - Calls for termination of remediation by regulators was premature

- S/S remediation *immobilised* contaminants

- Flux results corroborated in a separate PAH forensic assessment which found a common source of PAHs for soils, marine & aquatic sediments
  - Specific PAH forensic assessment results will be discussed in a separate platform presentation at this conference